Bottom Interaction in Ocean Acoustic Propagation

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LONG-TERM GOALS

The long term objective here is to understand the dominant physical mechanisms responsible for propagation and scattering over distances from tens to thousands of kilometers in the deep ocean where the sound channel is not bottom limited. The specific goal is to study the role of bottom interaction and bathymetry on the stability, statistics, spatial distribution and predictability of broadband acoustic signals observed just above and on the deep seafloor (greater than the critical depth). What is the relationship between the seismic (ground motion) noise on the seafloor and the acoustic noise in the water column? What governs the trade-offs in contributions from local and distant storms and in contributions from local and distant shipping? How effective is seafloor bathymetry at stripping distant shipping noise from the ambient noise field?

This project addresses "the effects of environmental variability induced by ocean internal waves, internal tides and mesoscale processes, and by bathymetric features including seamounts and ridges, on the stability, statistics, spatial distribution and predictability of broadband acoustic signals..." (quote from the Ocean Acoustics web page). Understanding long range acoustic propagation in the ocean is essential for a broad range of Navy applications such as the acoustic detection of ships and submarines at long ranges, avoiding detection of ships and submarines, long range command and communications to submerged assets, and improving understanding of the environment through which the Navy operates. The long-term objective here is to understand the dominant physical mechanisms responsible for propagation and scattering in the deep ocean where the sound channel is not bottom limited.

OBJECTIVES

The OBSAPS (Ocean Bottom Seismometer Augmentation in the Philippine Sea) experiment quantitatively compares the signal and noise levels in the Philippine Sea in the 50-400Hz band on the hydrophones and geophones at the seafloor to the hydrophones suspended up to 1 kilometer above the seafloor, for ranges from near zero to 250km. We also study seafloor ambient noise in the Philippine Sea in the band from 0.03 - 80Hz and compare it to other deep-water sites in the Pacific Ocean. Specific questions to be addressed include: i) Is there evidence for Deep Seafloor Arrivals in the Philippine Sea (water depths around 5500m) that are similar to the ones observed on NPAL04 (water depths around 5000m)? ii) What is the frequency dependence of the deep arrival structure from 50 - 400Hz? iii) What is the range dependence of the deep arrival structure out to 250km? iv) What is the azimuth dependence of the deep arrival structure? v) What are the relative SNRs of arrivals on

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vertical and horizontal geophones, co-located seafloor hydrophones and moored hydrophones (from 20m to 1000m off the bottom - 15 hydrophones at about 60m separation)? vi) What are the phase relationships between pressure and vertical and horizontal particle motion for deep seafloor arrivals and ambient noise? vii) What is the relationship between the observed deep arrival structure and the PE predicted arrival structure? viii) How far above the seafloor does the Deep Seafloor Arrival structure extend?

APPROACH

Three types of figures form the basis for the data reduction and analysis:

1) Time series of the time compressed traces as a function of range (for the eight 50km radials and the one 250km long line), as a function of azimuth (for the Star of David pattern) and as a function of time (for the station stops). For the 50km radials and Star of David we transmitted M-sequences at 77.5, 155 and 310Hz; for the 250km long-range tow we transmitted one M-sequence at 77.5Hz; and for the eighteen station stops we transmitted M-sequences at 77.5, 102.3, 155, 204.6 and 310Hz.

2) SNR summaries, similar to Figure 26 of the cruise report (Stephen *et al.*, 2011), are an excellent way to reduce an intensive data set (we transmitted for 11.5days) into a few meaningful parameters.

3) Spectrograms for all receivers. The fifteen HMs on the O-DVLA recorded for 24days (360 sensor-days at 1953.125sps). The sensors on the OBSs (four each for the three short-period OBSs, at 1000sps, one HM for each of the short-period OBSs, at 1953.125sps, and four each for the two long-period OBSs, at 200sps) recorded for about 12days (276 sensor-days). Continuous data for a total of 636 sensor-days was acquired. All instruments were recording during the typhoon on JD130 so we have samples of calm and rough conditions.

WORK COMPLETED

The major effort this year was re-processing, re-analyzing and publishing our observations and interpretation of Deep Seafloor Arrivals (DSFAs) observed on NPAL04 (Stephen *et al.*, 2009; Stephen *et al.*, 2008; Stephen *et al.*, 2012; in press). We concluded that the DSFAs observed on NPAL04 corresponded to energy diffracted from Seamount B and reflected from the sea surface back down to the seafloor receivers (Figures 1 to 3). We call these bottom-diffracted surface-reflected (BDSR) paths. DSFAs appear as the largest amplitude arrivals on the deep seafloor because of two factors. First, ambient noise on the deep seafloor (~5,000m) is almost 20dB quieter than at the conjugate depth (~4250m). Second, the usually large amplitude "accordion pattern" of PE predicted paths is strongly attenuated below the conjugate depth. The BDSR paths emerge above the ambient noise and the PE predicted paths. Although this work was a distraction from the analysis of the 2011 Philippine Sea Experiment, it was important to get this work published and it provides an important foundation for the interpretation of the Philippine Sea results.

Preliminary analysis of the OBSAPS data revealed that the observed ambient noise on hydrophone modules at the seafloor is very close to being system noise limited in the 5-20Hz band. The observed noise could be electronic noise in the acquisition system. This prompted an effort to deploy special high sensitivity hydrophones on the 2013 OBSANP experiment.

Also this year we carried out a review of previous marine geological work in the Philippine Sea and prepared an acoustic bottom model that was used to interpret data from other Philippine Sea Experiments.

RESULTS

The results of this year's work appear primarily in the Special Issue of JASA on Deep Water Ocean Acoustics that is about to appear in press. Stephen et al (2012; in press) report on the analysis of the NPAL04 data that identifies the BDSR path. Preliminary results from the OBSAPS (Ocean Bottom Seismometer Augmentation in the Philippine Sea) experiment are presented in Worcester et al (in press). The geological background on the Philippine Sea and our proposed acoustic model is described in Heaney et al (Heaney *et al.*, in press). We also worked with Simon Freeman on his analysis of T-phases in the Philippine Sea (Freeman *et al.*, in press).

IMPACT/APPLICATIONS

Leakage of energy into DSFAs will have at least three consequences. First, if energy leaks out of the waveguide in a systematic fashion, it will increase transmission loss for known modes in the waveguide. These will be scattering losses as opposed to intrinsic attenuation. If the leaked energy rumbles through the seafloor and re-emerges down range (as multipath arrivals), perhaps only to near-seafloor receivers, there will be less overall transmission loss (more signal). In this case interpretations may require new types of modes. Second, leakage into DSFAa will result in long-range detections and observations on non-traditional sensors such as deep boreholes in the seafloor in water depths well-below the critical depth. Third, the physics of short and long-range sound propagation that we are observing in the controlled-source transmissions also applies to local and distant shipping noise. For example, the DSFAs observed on NPAL04 provided a mechanism for taking long-range energy from 4250m depth into the deep shadow zone at 5000m depth. So the presence of DSFAs on various sensors requires a re-evaluation of the signal and noise energy budgets.

TRANSITIONS

Transitions to 32ASW project "Behavior of very low frequency near bottom ambient noise in deep water".

RELATED PROJECTS

LOAPEX - ONR Award Number N00014-1403-1-0181

SPICEX - ONR Award Number N00014-03-1-0182

PhilSea09 and PhilSea10 - ONR Award Number N00014-08-1-0840

OBSAPS - ONR Award Number N00014-10-10994 and N00014-10-1-0990.

OBSANP - ONR Award Number N00014-10-10987 and N00014-12-M-0394

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PUBLICATIONS

Stephen, R.A., Bolmer, S.T., Udovydchenkov, I.A., Worcester, P.F., Dzieciuch, M.A., Andrew, R.K. , Mercer, J.A., Colosi, J.A., and Howe, B.M., in press. Deep seafloor arrivals in long range ocean acoustic propagation. J. acoust. Soc. Am.

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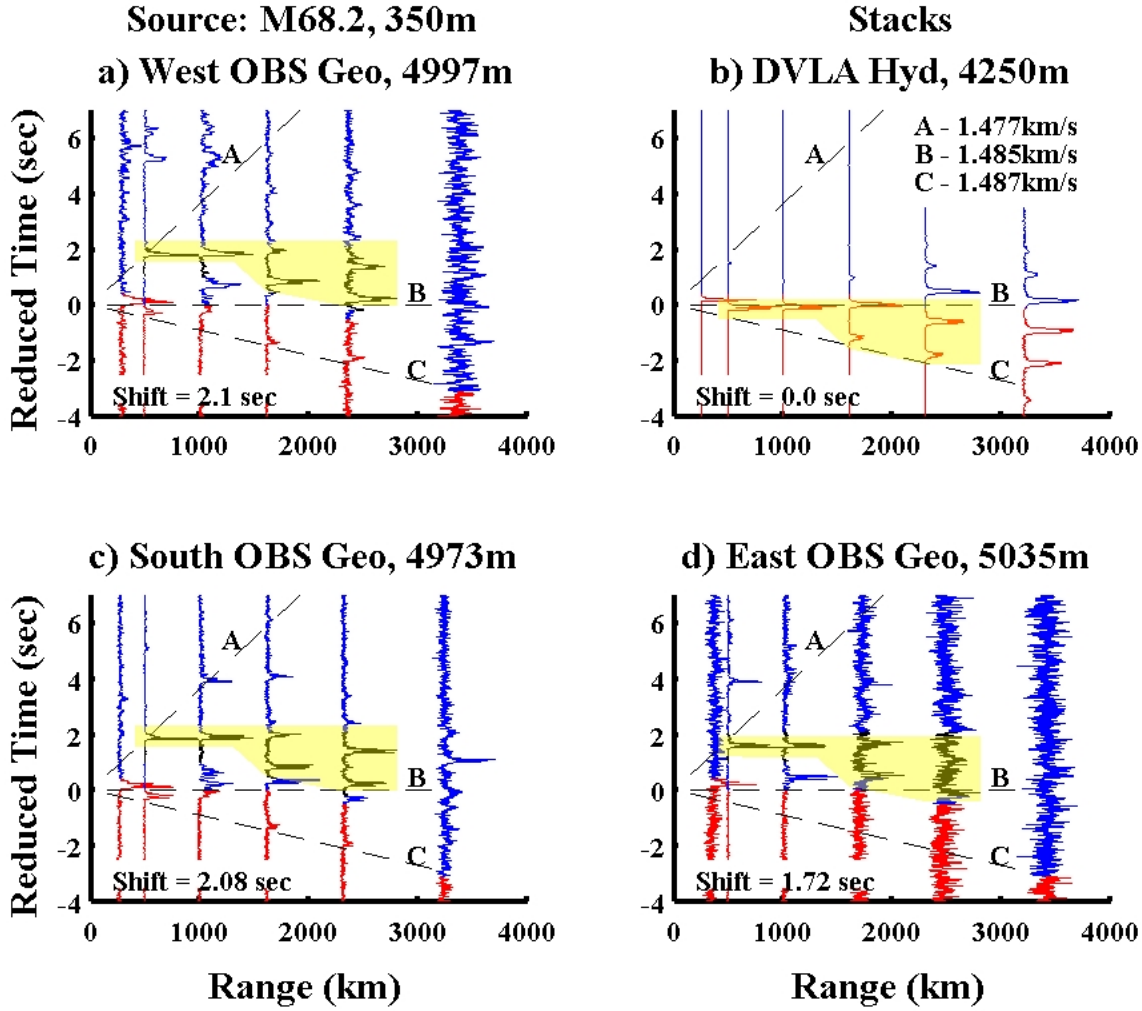

***Figure 1:** Stacks of the replica-correlated traces are displayed as a function of range for DVLA-4250 and all three of the OBSs that returned data. The nominal ranges are 250, 500, 1000, 1600, 2300 and 3200km. Reduced time is the actual travel time from the source minus the range divided by 1.485km/sec. The red section of each trace indicates the PE predicted arrivals and the blue trace indicates deep shadow-zone and deep seafloor arrivals as discussed in Stephen et al. (2009). The yellow region is the same shape on all four figures but has been shifted in time as indicated. Dashed lines correspond to three relevant speeds: A- 1.477km/s - the apparent sound speed of the latest arrival at 500, 1000 and 1600km range, B - 1.485km/s - the apparent sound speed of the largest PE predicted arrival on DVLA-4250, which seems to separate the known early arrivals from the late unknown arrivals, and C - 1.487km/s - the apparent sound speed of the earliest arriving energy at the OBSs and DVLA-4250. [Fig_02_OBS_Stacks_5_a4_new.pdf]*

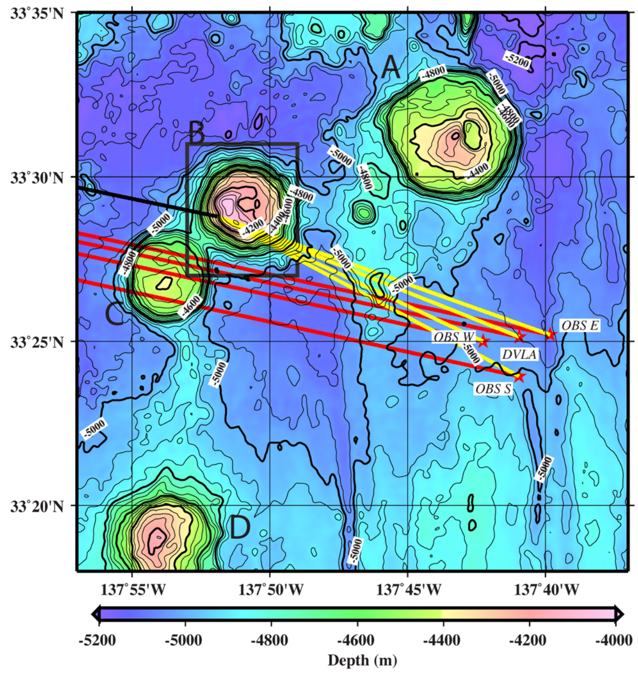

Figure 2: The locations of the three OBSs and the DVLA with their geodesic paths (red lines) to the source locations are overlain on swath map bathymetry. The deep seafloor arrival pattern on the OBSs (Figure 1) and the bottom-diffracted surface-reflected arrivals on DVLA-4250 are consistent with conversion from a PE predicted source-to-receiver path (black line) to a bottom-diffracted surface-reflected seamount-to-receiver path (yellow lines). [Fig_05_VLA_region_6.tif]

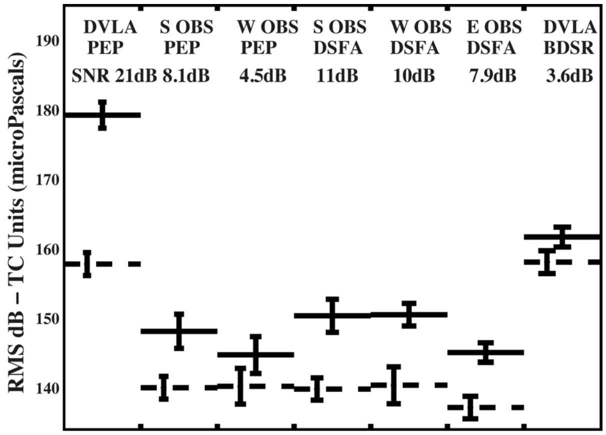

Figure 3: Quantifying signal (horizontal solid lines) and noise (before the signal, horizontal dashed lines) for the seven major arrival-receiver combinations at 500km range (T500). The three arrival types are: PE predicted (PEP), deep seafloor arrivals (DSFA), and bottom-diffracted surface-reflected (BDSR). The standard deviations of the 473 receptions that were cleanly received on all three OBSs (south, west and east indicated by S OBS, W OBS and E OBS respectively) and DVLA-4250 (DVLA in this figure) are indicated by the vertical error bars. The signal-to-noise ratio, the difference between the solid and dashed lines, is given along the top for each arrival. All signal and noise levels are RMS values in the units of the time compressed pressure time series in microPascals. For the OBSs, vertical particle motion has been converted to "pseudo-pressure" as explained in Stephen et al {Stephen, in press #14949}. [Fig_12_Geo_RMS_T500_S&N_Summary_2012_Noise1_7b.tif]